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Original Article

The classical supraorbital minicraniotomy to approach the areas of origin of anterior skull base meningiomas: Anatomical nuances influencing accessibility, operability, and frontal lobe retraction

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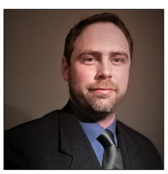

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ABSTRACT

Background: The classical supraorbital minicraniotomy (cSOM) constitutes a minimally invasive alternative for the resection of anterior skull base meningiomas (ASBM). Surgical success depends strongly on optimal patient selection and surgery planning, for which a careful assessment of tumor characteristics, approach trajectory, and bony anterior skull base anatomy is required. Still, morphometrical studies searching for relevant anatomical factors with surgical relevance when intending a cSOM for ASBM resection are lacking.

Methods: Bilateral cSOM was done in five formaldehyde-fixed heads toward the areas of origin of ASBM. Morphometrical data with potential relevant surgical implications were analyzed.

Results: The more tangential position of the cSOM with respect to the olfactory groove (OG) led to a reduction in surgical freedom (SF) in this area compared to others ($P < 0.0001$). Frontal lobe retraction (FLR) was also higher when approaching the OG ($P < 0.05$). Olfactory nerve mobilization was higher when accessing the planum sphenoidale (PS), tuberculum sellae (TS), and anterior clinoid process (ACP) ($P < 0.0001$). OG depth and the slope of the sphenoid bone between the PS and TS predicted lower SF and higher frontal retraction requirements along the OG and TS, respectively ($P < 0.05$). In contrast, longer distances to the ACP tip predicted lower SF over this structure ($P < 0.01$).

Conclusion: Although clinical validation is still needed, the present anatomical data suggest that assessing minicraniotomy's position/extension, OG depth, the sphenoid's slope, and distance to ACP-tip might be of particular relevance to predict FLR, maneuverability, and accessibility when considering the cSOM for ASBM resection, thus helping surgeons optimize patient selection and surgical strategy.

Keywords: Anatomy, Classical supraorbital approach, Meningioma, Skull base

INTRODUCTION

The use of classical supraorbital minicraniotomy (cSOM) constitutes a minimally invasive transcranial alternative to standard pterional, frontolateral, and sub-frontal craniotomies for the treatment of pathological processes within the rostral skull and brain, including the resection of anterior skull base meningiomas (ASBM).[10,21,24,26] Propagated during the ‘90s, the supraorbital approach enables a tailored exposure of deep structures through a minimal opening, reducing the need for excessive brain exposure and retraction and sparing the superficial temporal artery and Sylvian fissure dissection.[14,16,17] Furthermore, the short eyebrow incision and minimal soft tissue and temporal muscle dissection reduce the risk of large scars or muscle atrophy, providing excellent cosmetic results.[14] Although the working area in depth during a cSOM does not significantly differ from wider craniotomies, a limitation of this approach is the reduced maneuverability of microsurgical instruments through the narrower craniotomy boundaries and the restricted possibility to modify the microscope’s tilt and approach trajectories. For the specific case of ASBM resection, this may eventually lead not only to a longer time required to remove the tumor but also to considerable difficulties in managing eventual intraoperative complications.[21]

When facing the questions of whether a cSOM may be effective and safe for ASBM resection and which specific technical considerations may be required for surgery, three main issues are to be assessed preoperatively. First, the evaluation of tumor characteristics, such as size, growing pattern, and relationship (possible adherence) to main neurovascular structures, is key for predicting the feasibility of debulking and dissecting the tumor dome using a cSOM, the amount of brain retraction required for this task, potential risks of the neurovascular lesion, and the possibility to solve them intraoperatively through the small craniotomy. Second, assessing the spatial relationship between the craniotomy’s position and the area where the tumor is located is particularly important in keyhole approaches (as is the case of the cSOM) to foresee limitations for tumor resection or intraoperative complication management driven by an eventual too tangential approach trajectory or the presence of interposing structures along the narrower access route. Last but not least, evaluating the individual bony skull base anatomy is fundamental to predict the accessibility through the minicraniotomy to the most basal portions of the tumor and its matrix (especially in deep areas such as the olfactory groove [OG]) and the amount of brain retraction required to work in this area. A correct visualization and instrument maneuverability along the matrix are important to avoid leaving potentially removable tumor remanent, spare neurovascular damage (especially next to the anterior clinoid or tuberculum sellae [TS]), as well as enable managing eventual complications (such as bleedings coming from this often highly vascularized area) or unintended dural openings, associated with cerebrospinal-fluid leaks. On the other hand, visualization and maneuverability to get access to deep regions of the anterior skull base should be accomplished, minimizing brain retraction, which may otherwise increase the risk of cerebral contusion, swelling, and postoperative neurological deterioration.

To date, most of the recommendations for surgery performance and patient selection for ASBM resection through a cSOM are based on analyzing tumor-specific features, such as size, growing pattern, and relationship to neurovascular structures.[5,6,10,15,21,24] Although much has been published on supraorbital approaches, anatomical hard-data focusing on the other two relevant factors to be evaluated in case of considering a cSOM for the specific case of ASBM resection (i.e., craniotomy position/approach trajectory and specific anterior skull base bony features that may influence the maneuverability and brain retraction) are still lacking and, from our point of view, urgently needed. Therefore, the present work is aimed to provide relevant anatomical and morphometrical information, which, together with already available tumor-specific considerations, may be useful for neurosurgeons to optimize patient selection and plan the surgical strategy when considering the resection of ASBM through a cSOM.

MATERIALS AND METHODS

Five adult human head specimens, conserved through arterial perfusion with a formaldehyde solution of 40 g/L and subsequent formaldehyde immersion within humidity chambers, were subjected to bilateral cSOM, completing a total of $n = 10$ supraorbital approaches. Dissections were performed following strict hygienic and ethical standards.

The target regions were defined as those where ASBM usually arise, namely, the OG, planum sphenoidale (PS), TS, and anterior clinoid process (ACP). Heads were mounted on a 19 × 19 cm quadrangular holder and fixed at 4 points with adjustable pins. The surgical technique resembled the one used in the clinical series for the resection of ASBM.[21] The head was retroflexed 10–15° and rotated 20–60° to the opposite side during intracranial dissection, depending on the anatomical target area to be approached (20° to the lesser sphenoid wing and ACP, 30° to the PS and TS, and 45–60° to the OG). The eyebrow skin incision was placed lateral to the supraorbital notch and extended laterally a few mm beyond the superior temporal line. Dissection of the orbicularis oculi was done 1 cm above the orbital rim and reflected caudally toward the eyelid. The temporal muscle was separated 1 cm cranially from the superior temporal line to avoid injury to the zygomatic branch of the facial nerve. A burr hole was placed at the junction between the superior temporal line and the zygomatic process of the frontal bone, followed by an osteoplastic craniotomy. All craniotomies were allocated 0.5 cm lateral to the supraorbital notch and extended 2 cm over the orbital rim and 3 cm posterolaterally [Figure 1a]. The inner cortical layer of the orbital rim was

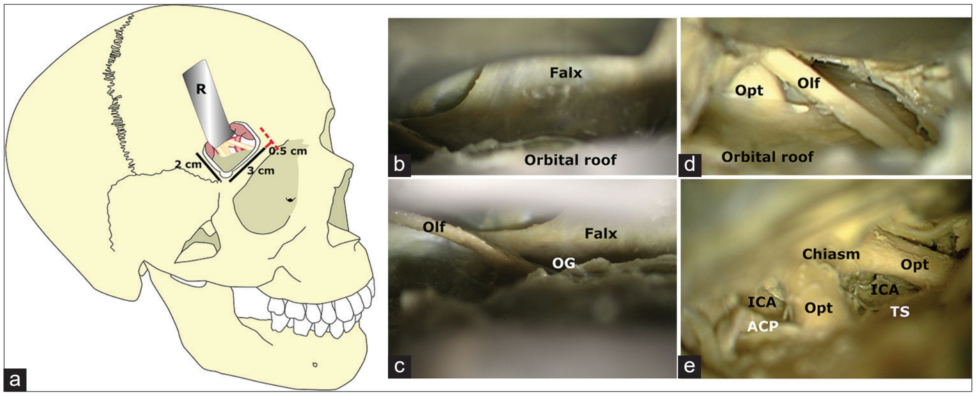

Figure 1: Craniotomy landmarks and anatomical dissections. (a) The medial boundary of each classical supraorbital minicraniotomy was located 0.5 cm lateral (red line) to the supraorbital notch (red dotted line), from which all craniotomies extended 3 cm laterally and 2 cm cranially. (b-e) After placing a single brain retractor (R) below the frontal lobe, a stepwise anterior skull base dissection was carried on. A careful exposure of the anterior fossa and related relevant neurovascular structures was accomplished before morphometrical assessment as depicted from more anterior to posterior. ACP: Anterior clinoid process; ICA: Internal carotid artery; OG: Olfactory groove; Olf: Olfactory nerve, Opt: Optic nerve, TS: Tuberculum sellae.

drilled off to facilitate the introduction of microinstruments, and the orbital roof was smoothed. The dura was opened in a U-shaped manner. A single brain retractor was placed subfrontally, and microsurgical dissection was performed in a stepwise fashion, exposing the ipsilateral OG, PS, TS, and ACP [Figures 1a-e].

Assessed morphometrical parameters included the distances and approach angles to all the structures mentioned above. Parameters were recorded in relation to the craniotomy's midpoint (situated at the caudal rim of the craniotomy exactly between the lateral and medial margin) at the outer skull [Figure 2a]. As described for paramedian supra cerebellar infratentorial approaches,[19] the approach angle was measured on the axial plane and described as the angle between the straight line connecting the target structure with the craniotomy's midpoint and the reference line (0°), which runs parallel to the midline [Figure 2a]. To assess frontal lobe retraction (FLR), the methods applied in previous publications were also used.[20,22] In this case, we measured the distance between the frontal lobe and the directly underlying orbital roof after applying a single retractor over the inferior frontal cortex to achieve the optimal OG, PS, TS, and ACP exposure. The olfactory nerve mobilization required to access each target area was also recorded, as the nerve represented the sole interposing structure along the anterior cranial base. We measured the depth of the OG at a coronal level 2 cm deeper than the outer craniotomy's edge after having smoothed the orbital roof Olfactory groove's depth (OGD) [Figure 2b]. The angle formed by the PS and the slope descending into the sella turcica (termed "sphenoid angle," SA) was also measured [Figure 2c]. Finally, we assessed the surgical freedom (SF) obtained with a cSOM over the OG, PS, TS, and ACP in an identical manner as thoroughly described and validated in a previous publication.[19] In this case, the SF represents the area covered 3 cm above the craniotomy by a free-moving dissector with its tip fixed on each of the above-mentioned anatomical landmarks [Figure 2d]. To calculate this area, the four extreme dissector positions 3 cm above the craniotomy are marked using malleable wires fixed to the lab's desk while moving the dissector as much as possible in craniocaudal and mediolateral directions without allowing its distal tip to lose contact with the selected anatomical landmark. The distances between the edges (corresponding to the sides of a polygon) are measured, and the area (i.e., SF) is then easily calculated arithmetically.[19]

Statistical analysis

For statistical analysis, Statistical Package for the Social Sciences Statistics 19.0 v (IBM Corp., Armonk, NY, USA) and GraphPad Prism 9.0.0 (GraphPad Software Inc., San Diego, CA, USA) were used. All data were subjected to a descriptive data analysis. Shapiro–Wilk goodness of fit tests were done to determine the parametric or non-parametric distribution of each variable. Since a normal distribution could be assumed for all variables, central tendency measures are expressed as the arithmetic mean and its dispersion as the standard deviation.

Student-*t*-tests and analysis of variance (ANOVA) were used for comparing two and three or more means, respectively. The effect size for significant ANOVA *P*-values was expressed as partial eta-square (η_p^2). Correlation analyses were performed calculating Pearson's r correlation coefficient. The respective level of significance is identified as follows: $^{****}P < 0.0001$, $^{***}P < 0.001$, $^{**}P < 0.01$, and $^{*}P < 0.05$.

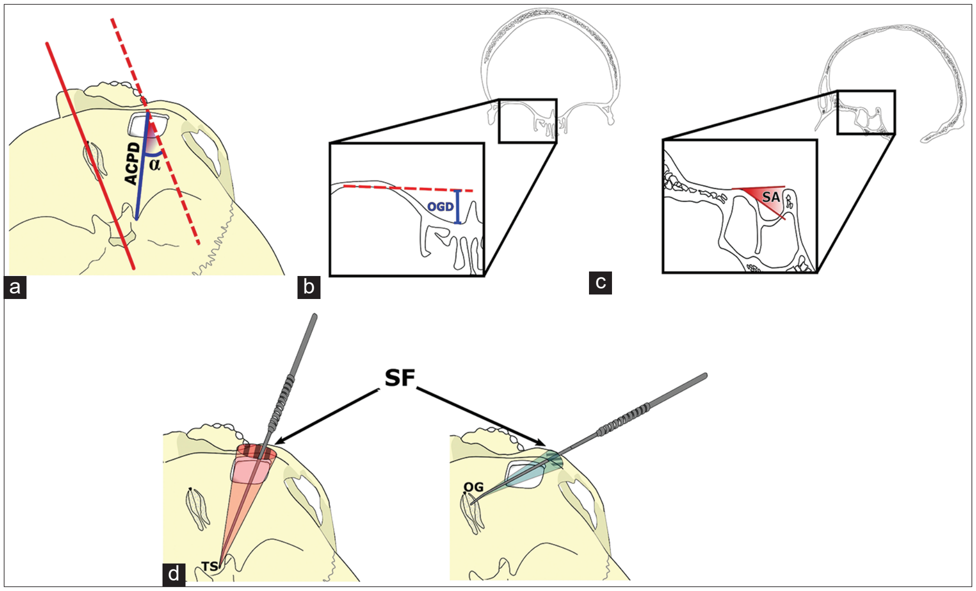

Figure 2: Schematic representation of morphometrical measures. (a) The distances to all assessed target structures, in this example, the distance to the anterior clinoid process (ACPD, blue line) ACPD (blue line), were measured from the craniotomy's midpoint, whereas the approach angles (α) were taken in relationship to a reference axis (red dotted line) running parallel to the midline. (b) The olfactory groove's depth (OGD) was measured in the coronal plane with respect to the orbital roof after smoothing its inner bony layer (red dotted line). (c) The sphenoid angle (SA) was measured as the slope descending toward the sella with respect to the planum sphenoidale's axis. (d) Surgical freedom (SF) (striped pattern) was assessed as the area covered 3 cm above the craniotomy by a free-moving dissector with its tip fixed on each of the target landmarks. OG: Olfactory groove, TS: Tuberculum sellae.

RESULTS

Distances and approach angles to the OG, PS, TS, and the tip of the ACP (ACPD) are depicted in Table 1. FLR and olfactory nerve mobilization required, as well as SF obtained when approaching the structures mentioned above, are likewise summarized in Table 1.

The approach angle increased from lateral toward medial and anteromedial structures, reaching a maximum of 59 ± 3° for the OG. The most distant structures targeted through the cSOA, that is, the tip of the ACP and the TS, were found at distances of 67.9 ± 2.2 and 69.1 ± 1.1 mm, respectively. OGD averaged 12.5 ± 1.9 mm and the SA 53.6 ± 7°. Mobilization of the olfactory nerve was specifically required when approaching the PS, TS, and ACP. A significantly lower olfactory nerve mobilization (mostly passive due to frontal lobe elevation) was required when approaching the olfactory bulb, as demonstrated in univariate ANOVA ($F[4,50] = 178,621$, $P < 0001$, $\eta_p^2 = 0.941$) and T-tests (all $P < 0.0001$), [Figure 3a].

SF on the OG, averaging 188.8 ± 23.6 mm^2, was significantly lower when compared to the other assessed regions, as demonstrated in univariate ANOVA ($F[3,36] = 33$, $P < 0.0001$, $\eta_p^2 = 0.726$) and T-tests (all $P < 0.0001$); [Figure 3b]. Even though SF within the PS showed a tendency to be greater than on the ACP or the TS, *t*-test comparisons between each area yielded no significance. There was also no statistical difference between the SF obtained on the ACP and the TS. A strong negative correlation was found between OGD and SF within the OG ($r = -0.991$, $P < 0.0001$). When specimens with OGD greater or lower than 12 mm were compared, a significant increase of SF was observed in cases with OGD ≤ 12 mm, as shown by a *t*-test ($P < 0.01$); [Figure 4a].

In addition, a strong negative correlation was found between SA amplitude and the SF along the TS ($r = -0.787$, $P < 0.01$). When specimens were divided according to SA, *t*-tests demonstrated a significant SF reduction along the TS ($P < 0.05$) for those with an SA > 55° [Figure 4b]. A similar relationship was observed between ACPD and the SF over the ACP. Longer distances to the anterior clinoid's tip correlated negatively with SF on this structure ($r = -0.895$, $P < 0.001$). In this case, a significant reduction in SF was observed for ACPD > 68 mm ($P < 0.05$); [Figure 4c].

The FLR required to achieve maximal exposure of the analyzed structures was maximum for the OG, followed by the TS, with average values of 13.4 ± 1.4 and 13.2 ± 1.3 mm, respectively. In contrast, FLR was minimal to the PS, averaging 11.5 ± 1.2 mm [Table 1]. Univariate ANOVA confirmed an overall significant difference in terms of

Table 1 : A summary of morphometrical data obtained when approaching the areas of origin of ASBM through a cSOM.

	Distance (mm)	Approach angle (°)	Frontal lobe retraction (mm)	Olfactory nerve mobilization (mm)	Surgical freedom (mm²)
Olfactory bulb	42.1±1.9	58.6±3.1	13.4±1.4	2.7±0.7	188.8±23.7
Planum sphenoidale	56.6±2.5	40.4±3.3	11.5±1.2	10.5±1	381.6±46.2
Tuberculum sellae	69.1±1.1	36.7±3.3	13.2±1.3	11.2±0.9	336.5±65.3
Anterior clinoid process	67.9±2.2	24.6±1.4	12.3±1.8	10.1±1.3	357.8±46.9

cSOM: Classical supraorbital minicraniotomy, ASBM: Anterior skull base meningiomas

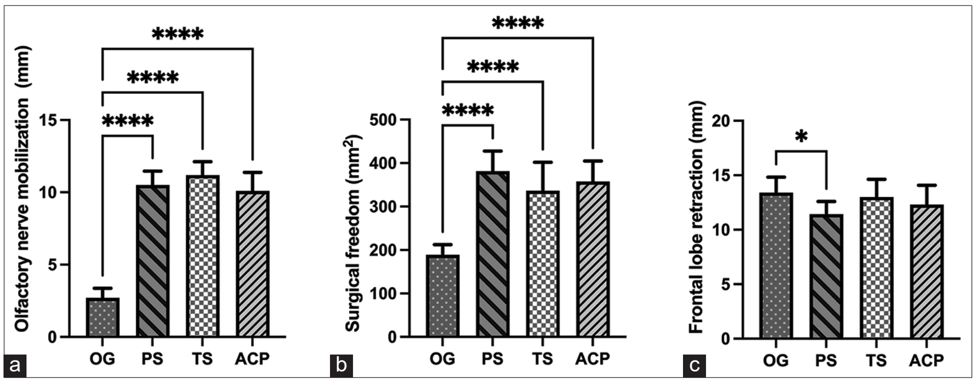

Figure 3: (a) Olfactory nerve mobilization, (b) surgical freedom, and (c) frontal lobe retraction required to reach the target anatomical landmarks assessed on the anterior skull base. Bars represent means ± 2 standard error. OG: Olfactory groove, PS: Planum sphenoidale, TS: Tuberculum sellae, ACP: Anterior clinoid process. * p<0.05, **** p<0.0001

FLR requirements to approach ASBM-typical locations ($F[3,36] = 3,340$, $P < 0.05$, $\eta_p^2 = 0.329$). *T*-tests demonstrated that this effect was mainly due to a significantly greater FLR required to access the OG compared to the PS ($P < 0.05$), [Figure 3c]. The amount of FLR required to expose the ACP was 12.3 ± 1.7 mm and did not differ significantly from the other structures approached. OGD positively correlated with greater FLR required to approach the OG ($r = 0.953$, $P < 0.0001$). A significantly greater FLR was required to maximally expose the OG in specimens with OGD > 12 mm, as demonstrated in a T-test ($P < 0.01$), [Figure 4a]. The SA did not correlate with the required FLR when approaching the PS ($r = 0.342$), but a larger SA correlated with a higher FLR needed to operate on the TS ($r = 0.916$, $P < 0.001$). A higher FLR to the TS was required for SA > 55° ($P < 0.01$), [Figure 4b]. There was no significant correlation between ACPD and the FLR required to expose the ACP ($r = 0.441$), a fact that remained below significance after dividing the group by ACPD longer or shorter than 68 mm [Figure 4c].

DISCUSSION

This study was designed to analyze factors regarding approach angles and trajectories, as well as specific bony skull base features, which have not been thoroughly addressed in the published literature but may have relevant implications for patient selection and surgical performance when considering a cSOM for the specific case of ASBM resection. Our results demonstrate that given the position of the cSOM and the resulting approach trajectories to the areas where ASBM arise, the surgical maneuverability (represented by the SF) is significantly more limited along the OG in comparison to other more straightforward-located structures, such as the TS and PS. Approaching the TS, ACP, and PS requires, however, a significantly higher amount of olfactory nerve mobilization. When applying a cSOM, the steeper trajectory toward the OG significantly increases the requirement of brain retraction in the depth of this area. The most relevant findings in our work were that OGD and the increasing slope toward the sella (SA) represent important predicting factors for SF and FLR along the OG and the TS, whereas an increasing ACPD may predict reduced surgical maneuverability within the ACP. We found no specific bony anatomical parameters influencing the SF or FLR required to access the PS.

Prior morphometrical data focusing on the working space around vascular elements, such as the middle cerebral artery (MCA) bifurcation, the most distal point of the ipsi- or contralateral posterior cerebral artery and the contralateral MCA, demonstrated that the cSOM might eventually provide similar surgical working space in depth as the pterional and orbitozygomatic approach if patients are carefully

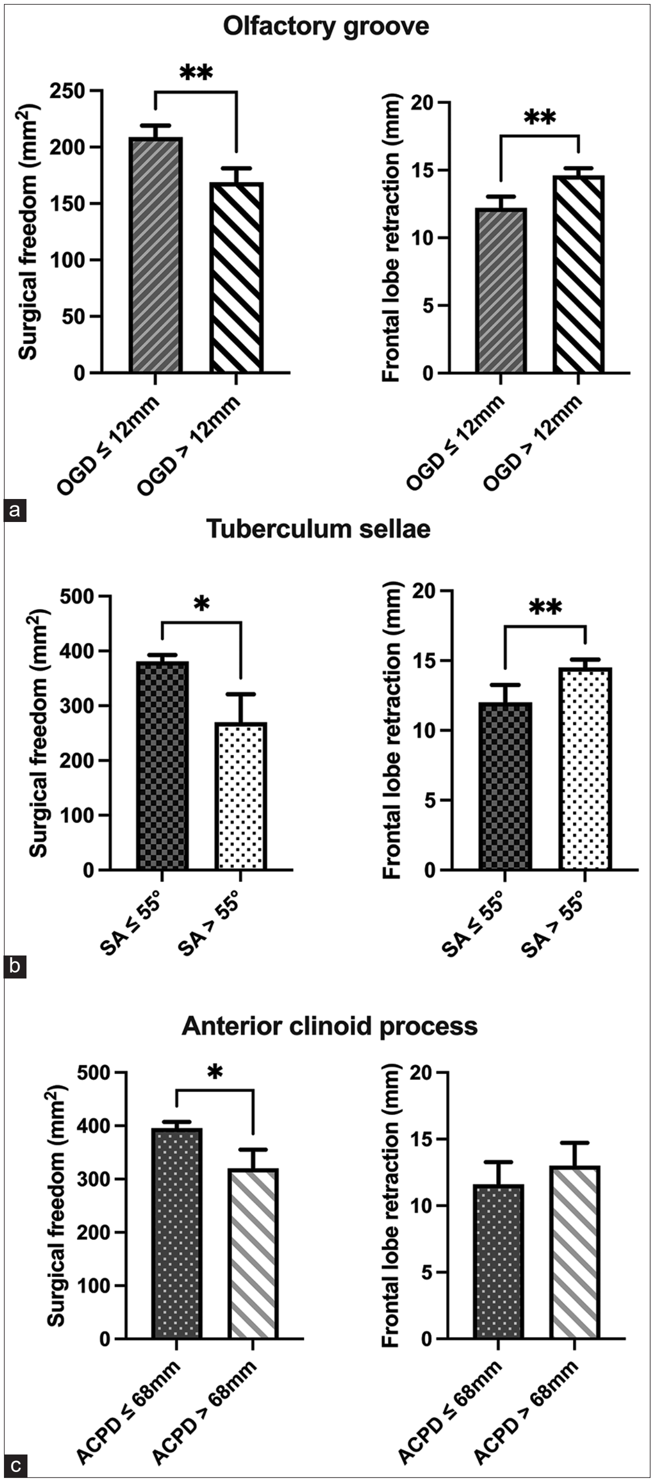

Figure 4: Analysis of surgical freedom (left) and frontal lobe retraction (right) required when approaching the (a) olfactory groove, (b) tuberculum sellae, and anterior clinoid process (c) according to olfactory groove's depth (OGD), sphenoid angle (SA), and distance to the anterior clinoid process tip (ACPD), respectively. Bars represent means ± 2 standard error. *p<0.05, ** p<0.01.

selected.[7] Despite its focus on vascular landmarks and not tumor locations, the authors observed that the selection of a cSOM should primarily depend on working angles rather than the area to be exposed. Consistent with this observation, our morphometric data demonstrated that SF was significantly reduced in the working area localized at more tangential angles with respect to the craniotomy's plane, such as the OG (see also schematic representation in Figure 2d). This more limited SF to access the OG may also partially explain observational findings evidencing longer surgical resection times for OG meningiomas through a supraorbital approach in comparison to ASBM of other locations.[21] Although these prolonged resection times may also be related to other factors (such as the larger sizes shown by these tumors at the moment of diagnosis in comparison to those in locations with a closer relationship to the optic apparatus), the more tangential and steeper downward approach trajectory to the OG using a cSOM is surely responsible for a more parsimonious performance of tumor resection. Based on these anatomical results, a first recommendation for surgeons intending the resection of an OG meningioma through the cSOM would be to increase slightly the temporal muscle detachment, seeking a light posterolateral craniotomy extension/displacement. In this way, the more lateralized supraorbital craniotomy may facilitate the instrument's maneuverability along the most rostral portions of the skull base, including the OG. However, while performing this maneuver, special care should be taken during soft tissue and muscle dissection to avoid stretching the facial nerve within the zygomatic fat pad with the subsequent risk of orbicular muscle palsy.

Another observation of our study was that after applying the cSOM, the trajectory to the target structures behind the olfactory bulb was partially obstructed by the olfactory nerve. Consequently, olfactory nerve mobilization was analyzed and the results demonstrated a significant amount of mobilization needed for accessing the PS, TS, and ACP. Olfactory nerve dysfunction constitutes a frequently reported side effect in ASBM surgery.[3,12,23,25] In the case of OG meningiomas, bilateral olfactory bulb involvement and intraoperative cribriform plate coagulation are responsible for hypo/anosmia, evidenced by up to 81% of the patients postoperatively.[2,3,12,23-25] However, in cases of TS meningiomas, the rate of postoperative hyposmia is still estimated to be 7–15% and related to the need to mobilize the olfactory nerve to get access to the tumor through the subfrontal/supraorbitary route.[12,21,23] Our anatomical data go beyond this and demonstrate that the olfactory nerve mobilization required to approach the PS and ACP through the cSOM is as high as during the access to the TS, pinpointing a probable similar risk of olfactory dysfunction for accessing all regions behind the olfactory bulb through a cSOM. Although a remarkable capacity of the olfactory nerve for neural regeneration and recovery has been reported as long as the nerve's continuity is respected,[11] there is a lack of clinical evidence to establish the amount of mobilization that the nerve may tolerate during surgery and its functional consequences. Quantitative olfactory disorders can have an impact on the quality of a patient's life, leading in some cases to weight loss or depression, although this is especially after complete bilateral loss of olfactory function.[1,4] In addition, olfactory loss can be associated with a markedly increased risk of exposure to hazardous events in everyday living, such as intake of spoilt food and burning of meat, although patients with posttraumatic anosmia have been shown to acquire an elevated gustatory threshold, which tends to compensate the deficit.[9,18] Indeed, the need for mobilization of the olfactory nerve does not constitute a contraindication for the supraorbital approach, and other classical approaches may not completely avoid its mobilization as the frontal lobe (and consequently the olfactory nerve) must be elevated to access the anterior skull base. However, the use of a supraorbitary route may, therefore, increase the risk of olfactory nerve dysfunction after surgery (even if the tumor is located behind and not within the olfactory bulb) in comparison to other more lateral approaches and this risk should be discussed with the patient prior to surgery. If such a complication is not well tolerated, applying a conventional pterional craniotomy and a more lateral approach trajectory to the TS, PS, and ACP (including eventually a partial anterior opening of the Sylvian fissure to release the frontal lobe) may be preferred. Otherwise, special care should be taken when progressing into the depth of the anterior fossa toward the PS, TS, and ACP through a cSOM to minimize the shear forces applied to the olfactory nerve and, with it, the risk of postoperative olfactory nerve dysfunction.

The present results also endorse the relevance of specific bony skull base features for predicting the needs of FLR and surgical maneuverability along the areas where the matrix end most basal portions of ASBM are located. First, we observed that the deeper the OG, the greater the FLR required and the lower the SF to operate in this area, suggesting that preoperative evaluation of OGD should be mandatory when approaching the OG through a cSOM. Again, although the presence of a deep OG does not necessarily implicate the contraindication of a supraorbital approach, it may have direct consequences on the surgical technique. In cases of meningiomas arising from an OG deeper than 12 mm, the inclusion in the surgical armamentarium of neuro endoscopy with 30°-optics, as well as angled microinstruments will be particularly useful for safe tumor resection along the deep-located matrix, increasing SF, and minimizing brain retraction. Since performing skilled surgical maneuvers guided by angled endoscopic views may represent a difficult task for the not-experienced neurosurgeon, considering this factor before surgery may be important to prevent unexpected difficulties during deeper tumor detachment or deal with eventual intraoperative complications (e.g., in case of needing to seal a cerebrospinal-fluid fistula along the cribriform plate or cauterizing bleedings along the tumor matrix coming from ethmoidal artery branches). In addition, the presence of OG deeper than 12 mm indicates that, independently of tumor size, surgical measures to maximize brain relaxation (such as opening the prechiasmatic cistern or placing a lumbar drain before surgery) are strongly encouraged to reduce the forces applied with the retractors. Similarly, a steeper sphenoidal slope (i.e., SA) was associated with a reduced SF along the TS, a fact related to a higher limitation to move the instruments along a sinking surface below the approach's plane and higher FLR required. Based on these data, we suggest that preoperative detection of a SA >55° should alert the surgeon about an increasing difficulty in operating on the basal portions of the tumor in this area, thus highlighting the need to use endoscopic assistance with downward 30°-optics and curved microinstruments to overcome possible limitations. Since the prechiasmatic cistern is usually occupied by TS meningiomas, the presence of a SA >55° could be considered a practical reference for surgeons to consider cerebrospinal fluid release through a lamina-terminalis opening or preoperative placement of lumbar drainage, achieving in this way maximal brain relaxation and reducing the pressure applied by the retractor over the frontal lobe.

In the case of the ACP, the more frequent interposition of perforating arteries around the optic nerve and supra clinoid carotid artery acted as the main factor linked to SF reduction in specimens with longer ACPD. This fact may also explain why only SF and not FLR were influenced by ACPD since not the approach's slope, but rather obstructing vascular elements increased the difficulties to access the area. ACPD could be eventually used to determine which patients may be candidates for a cSOM or whether a more lateral trajectory applying wider craniotomies (e.g., a front lateral craniotomy or a pterional approach with Sylvian-fissure dissection) should be preferred to circumvent hindering perforating arteries within the target area. On the other hand, since perforating arteries might be displaced toward the front, behind or above an ACP meningioma, it turns questionable in this case whether the sole calculation of ACPD may be useful to predict SF in cases of tumor or masses affecting the ACP directly. ACPD could probably play a clearer role in predicting surgical maneuverability in cases where the anatomy along the superior clinoid's surface is not distorted and the pathology is located posterior to the ACP (such, for example in posterior communicating aneurysms).[8,13] Further studies assessing the ACPD in real surgeries may enable clarify the relevance played by ACPD in the surgical scenario.

Table 2: Possible limitations driven by factors related to the approach's angle/trajectory and anterior skull base anatomy and recommendations for surgical troubleshooting when applying a cSOM to the areas where ASBM arise.

	Structure	Limitation	Troubleshooting
Approach angle/ trajectory	OG	The Target zone is located more tangential to the craniotomy, therefore reducing surgical freedom in comparison to other areas.	Increase temporal muscle detachment and displace/extend the craniotomy toward more posterolateral (CAVE: manipulation of the soft tissue beyond the frontal bone's zygomatic process should be gentle to avoid injuring the zygomatic branch of the facial nerve).
	PS TS ACP	Increased requirement of olfactory nerve mobilization to access the area.	Perform gentle olfactory nerve mobilization. Discuss with the patient the risk of postoperative newly onset transient or permanent hyposmia. If newly postoperative olfactory deficits are unacceptable for the patient, consider a more lateralized standard approach (e.g., pterional craniotomy), eventually with the partial opening of the Sylvian fissure.
Bony skull base anatomy	OG	OGD >12 mm may predict higher requirements of frontal lobe retraction and reduced maneuverability (SF) in the depth of the OG	Use neuro endoscopy with 30° downward optics to access the basal portions of the tumor and the matrix. Proceed to open the prechiasmatic cistern or place a lumbar drain to release CSF, relax the brain and minimize active retraction.
	TS	SA >55° may predict higher requirements of frontal lobe retraction and reduced maneuverability (SF) to operate along the TS	Use neuro endoscopy with 30° downward optics to access the basal portions of the tumor and the matrix. Consider placing a lumbar drain or opening the lamina terminalis for CSF release and brain relaxation (the prechiasmatic cistern is usually occupied by PS or TS meningiomas)
	ACP	ACPD >68 mm may predict reduced maneuverability (SF)	Eventually, consider a wide standard pterional craniotomy, which allows more versatility to alternate approach trajectories (more anteromedial/more posterolateral) to circumvent hindering perforating arteries within the target area.

cSOM: Classical supraorbital minicraniotomy, ASBM: Anterior skull base meningiomas, OG: Olfactory groove, PS: Planum sphenoidale, TS: Tuberculum sellae, ACP: Anterior clinoid process, CSF: Cerebrospinal fluid, SF: Surgical freedom

In summary, the anatomical data here presented provide new insights for patient selection and surgical performance when considering a cSOM for the resection of ASBM, going beyond the recommendations based basically on tumor features and endorsing the importance of considering additional factors associated with the approach's trajectory and bony anterior skull base anatomy [Table 2]. Given the pure anatomical nature of these data, validation in surgical patients will be required. In this context, taking together already published retrospective surgical data with the present anatomical nuances may be helpful to set the basis for future prospective surgical trials, aiming to determine and quantify the relevance of each of the different factors (tumor growing pattern and consistency, size, relationship to neurovascular structures, approach trajectory, anterior skull base anatomy, surgical technique, and neurosurgical skills) for case selection and safe and successful ASBM resection through the cSOM.

CONCLUSION

The cSOM enables a more esthetical and minimally invasive approach to ASBM, but the key to success relies on a very careful patient selection surgical planning and technical performance. Available retrospective surgical data provide useful recommendations for surgeons based mostly on tumor-related features. Our present results demonstrate that specific anatomical characteristics related to the approach trajectory and bony skull base are also relevant in the preoperative assessment when considering a cSOM to approach the areas where ASBM usually arise. Particularly, a more posterolateral craniotomy extension may be useful to overcome the more reduced surgical maneuverability along the OG. Furthermore, assessing OGD, SA, and ACPD seems to be of practical relevance for decision-making destined to avoid excessive FLR and maximize operability in the basal portions of OG, TS, and ACP meningiomas. Future prospective surgical trials should be encouraged to determine further the role played by all anatomical and tumor associated factors for the effective and safe performance of ASBM resections through the cSOM.

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Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Authors' contributions

Lucas Serrano Sponton, Eleftherios Archavlis, and Sven Kantelhardt conceptualized this study. Lucas Serrano Sponton performed anatomical dissections and measurements, analyzed the data, and wrote the original manuscript. Eleftherios Archavlis, Jens Conrad, Amer Nimer, Ali Ayyad, Elke Januschek, Daniel Jussen, and Marcus Czabanka edited the original manuscript. Sven Schumann administrated anatomical resources. Sven Schumann and SK administrated the project. All authors reviewed the manuscript critically and approved for publication of the content.

Ethical approval

The research/study was approved by the Institutional Review Board at Rhineland Palatinate Ethical Committee, number 2022-16595, dated October 14, 2022.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Blomqvist EH, Brämerson A, Stjärne P, Nordin S. Consequences of olfactory loss and adopted coping strategies. Rhinology 2004;42:189-94.
2. Ciurea AV, Iencean SM, Rizea RE, Brehar FM. Olfactory groove meningiomas. Neurosurg Rev 2012;35:195-202.
3. Dedeciusova M, Svoboda N, Benes V, Astl J, Netuka D. Olfaction in olfactory groove meningiomas. J Neurol Surg A Cent Eur Neurosurg 2020;81:310-7.
4. Deems DA, Doty RL, Settle RG, Moore-Gillon V, Shaman P, Mester AF, *et al*. Smell and taste disorders, a study of 750 patients from the University of Pennsylvania Smell and Taste Center. Arch Otolaryngol Head Neck Surg 1991;117:519-28.
5. Fatemi N, Dusick JR, de Paiva Neto MA, Malkasian D, Kelly DF. Endonasal versus supraorbital keyhole removal of craniopharyngiomas and tuberculum sellae meningiomas. Neurosurgery 2009;64:269-87.
6. Fernandes YB, Maitrot D, Kehrli P, de Tella Jr., Ramina R, Borges G. Supraorbital eyebrow approach to skull base lesions. Arq Neuropsiquiatr 2002;60:246-50.
7. Figueiredo EG, Deshmukh V, Nakaji P, Deshmukh P, Crusius MU, Crawford N, *et al*. An anatomical evaluation of the mini-supraorbital approach and comparison with standard craniotomies. Neurosurgery 2006;59:ONS212-20; discussion ONS220.
8. González-Darder JM, Quilis-Quesada V, Talamantes-Escribá F, Botella-Maciá L, Verdú-López F. Microsurgical relations between internal carotid artery-posterior communicating artery (ICA-PComA) segment aneurysms and skull base: An anatomoclinical study. J Neurol Surg B Skull Base 2012;73:337-41.
9. Hummel T, Nesztler C, Kallert S, Kobal G, Bende M, Nordin S. Gustatory sensitivity in patients with anosmia. Chem Senses 2001;26:1118.
10. Khan DZ, Muskens IS, Mekary RA, Zamanipoor Najafabadi AH, Helmy AE, Reisch R, *et al*. The endoscope-assisted supraorbital "keyhole" approach for anterior skull base meningiomas: An updated meta-analysis. Acta Neurochir (Wien) 2021;163:661-76.
11. Kobayashi M, Costanzo RM. Olfactory nerve recovery following mild and severe injury and the efficacy of dexamethasone treatment. Chem Senses 2009;34:573-80.
12. Komotar RJ, Starke RM, Raper DM, Anand VK, Schwartz TH. Endoscopic skull base surgery: A comprehensive comparison with open transcranial approaches. Br J Neurosurg 2012;26:637-48.
13. Park SK, Shin YS, Lim YC, Chung J. Preoperative predictive value of the necessity for anterior clinoidectomy in posterior communicating artery aneurysm clipping. Neurosurgery

2009;65:281-5; discussion 285-6.
14. Reisch R, Marcus HJ, Hugelshofer M, Koechlin NO, Stadie A, Kockro RA. Patients' cosmetic satisfaction, pain, and functional outcomes after supraorbital craniotomy through an eyebrow incision. J Neurosurg 2014;121:730-4.
15. Reisch R, Perneczky A. Ten-year experience with the supraorbital subfrontal approach through an eyebrow skin incision. Neurosurgery 2005;57:242-55.
16. Reisch R, Perneczky A, Filippi R. Surgical technique of the supraorbital key-hole craniotomy. Surg Neurol 2003;59:223-7.
17. Reisch R, Stadie A, Kockro RA, Hopf N. The keyhole concept in neurosurgery. World Neurosurg 2013;79:S17-e9-13.
18. Santos DV, Reiter ER, DiNardo LJ, Costanzo RM. Hazardous events associated with impaired olfactory function. Arch Otolaryngol Head Neck Surg 2004;130:317-9.
19. Serrano Sponton L, Alhoobi M, Archavlis E, Shaaban AT, Dumour E, Nimer A, *et al*. Endoscopic-assisted paramedian supracerebellar infratentorial approach to the posterior portion of the third ventricle. Anatomical study and surgical cases. J Neurosurg Sci 2022. Doi: 10.23736/S0390-5616.22.05622-3.
20. Sponton LS, Archavlis E, Conrad J, Nimer A, Ayyad A, Januschek E, *et al*. Variants of the anterior subtemporal approach to the Gasserian ganglion and related structures: An anatomical study with relevant implications for keyhole surgery. World Neurosurg 2023;176:e587-97.
21. Sponton LS, Oehlschlaegel F, Nimer A, Schwandt E, Glaser M, Archavlis E, *et al*. The endoscopic-assisted supraorbital approach for resection of anterior skull base meningiomas: A large single-center retrospective surgical study. J Neurol Surg B Skull Base 2023;84:349-60.
22. Sponton LS, Shaaban AT, Archavlis E, Alhoobi M, Nimer A, Conrad J, *et al*. Two-stage endoscopic assisted approach for large pineal region and falcotentorial meningioma: first stage paramedian supracerebellar infratentorial approach, second stage interhemispheric occipital transtentorial approach: Surgical cases and anatomical study. Neurosurg Rev 2022;45:1759-72.
23. Symon L, Rosenstein J. Surgical management of suprasellar meningioma: Part 1: The influence of tumor size, duration of symptoms, and microsurgery on surgical outcome in 101 consecutive cases. J Neurosurg 1984;61:633-41.
24. Telera S, Carapella CM, Caroli F, Crispo F, Cristalli G, Raus L, *et al*. Supraorbital keyhole approach for removal of midline anterior cranial fossa meningiomas: A series of 20 consecutive cases. Neurosurg Rev 2012;35:67-83.
25. Welge-Luessen A, Temmel A, Quint C, Moll B, Wolf S, Hummel T. Olfactory function in patients with olfactory groove meningioma. J Neurol Neurosurg Psychiatry 2001;70:218-21.
26. Zhang M, Wang L, Zhang W, Qi W, Wang R, Han XD, *et al*. The supraorbital keyhole approach with eyebrow incisions for treating lesions in the anterior fossa and sellar region. Chin Med J (Engl) 2004;117:323-6.

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